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NRL Reprint No. 8-53

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IN DIM LIGHT AND IN DARKNESS BY MEANS
OF THE PURKINJE IMAGES

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Reprinted from JOURNAL OF THE OPTICAL
SOCIETY, January 1953



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Measurement of Accommodation in Dim Light and in Darkness by Means of the Purkinje Images

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(Received September 16, 1952)

The state of focus of the eye in dim light and in total darkness was investigated by photographing the Purkinje images of a double aperture placed over a high speed flash lamp. Measurement of the photographed images showed that all subjects, when viewing a dim scene, remained focused for far vision. By subjective test, however, these subjects were myopic under the same conditions of dim light. The experimental results thus favor the theory that "night myopia" is a result of the aberrations of the eye and is not due to accommodation. The flash photographs taken in total darkness showed that three subjects remained focused for far vision; the fourth subject sometimes accommodated, by amounts varying between 0.5 and 1.5 diopter.

IN 1951 we reviewed much of the existing literature on night myopia and described new experiments which showed that the principal causes of the phenomenon are the aberrations in the eye, spherical aberration being the chief contributor.¹ Accommodation was found to be an unimportant factor by the following experiment. The subjects were required to fixate foveally a distant target with fine detail, and at the same time to determine subjectively the optimum spectacle correction for a dimly illuminated coarse grating target viewed by the dark-adapted parafovea. The subjects' usual night myopia appeared under these conditions, although accommodation was prevented by means of the foveally viewed target.

It was also shown that the change in the magnitude of night myopia with brightness could be explained on the basis of the undercorrected spherical aberration of the eye; the effect of the spherical aberration on the light distribution in the retinal image is such that a progressive change in focus is required to produce best contrast rendition of the test gratings, which must become coarser to be resolved visually as their bright-

ness is reduced. The essentials of this explanation were recently confirmed by the work of Hotchkiss, Washer, and Rosberry,² who found that, for photographic lenses having spherical aberration, the focal position for best contrast rendition varied with the coarseness of the grating test object.

Bouman and van den Brink³ in 1952 reported a study of night myopia, and proved independently that spherical aberration was partly responsible for the phenomenon. Otero⁴ and his collaborators, however, have recently described a new experiment leading to the conclusion that accommodative changes in the eye are the only important cause of night myopia. Otero's work is unusual in that his measurements of the refractive state of the eye were made by photographing the Purkinje images of a flash lamp, rather than by the usual subjective method which determines the spectacle correction producing maximum acuity in dim light. Otero chose three subjects who had especi-

¹ Hotchkiss, Washer, and Rosberry, *J. Opt. Soc. Am.* 41, 600 (1951).

² M. A. Bouman and G. van den Brink, *Ophthalmologica* 123, 100 (1952).

³ J. M. Otero, *J. Opt. Soc. Am.* 41, 942 (1951).

⁴ Koomen, Scolnik, and Tousey, *J. Opt. Soc. Am.* 41, 80 (1951).

ally distinct Purkinje images, and found that, when the eye was in total darkness, the second Purkinje image of the flash lamp was smaller than when the eye was adjusted for far vision. This indicated an increased accommodation in the dark of about 1.2 diopters. Although the measurements were made only in total darkness, Otero concluded that the same state of accommodation prevailed in dim light and was identical with the phenomenon of night myopia.

Since these results were contradictory to our own, we repeated Otero's experiments with our own subjects who, by the subjective test described above, showed little or no accommodation in dim light, but who nevertheless had substantial night myopia. Further, it seemed worth while to investigate Otero's assumption that the state of accommodation in total darkness is necessarily the state prevailing in dim light. It seemed quite possible that some eyes might accommodate slightly in darkness, in the absence of all visual stimuli, but that this tendency might disappear in dim light with binocular vision, since there are weak convergence and acuity cues for proper focusing. This was indeed found to be the case for one of our subjects; the others, however, did not accommodate, either in dim light or darkness.

EXPERIMENTAL METHOD

Our method of photographing the Purkinje images was similar to that used by Otero.⁴ Figure 1 shows the experimental apparatus. The light source (A) was a gas-filled discharge tube, mounted in a reflector and giving a flash of 500 microsecond duration. The reflector was covered with a sheet of black paper containing two circular holes of one centimeter diameter and separated vertically by about 6 cm between centers. The reflector

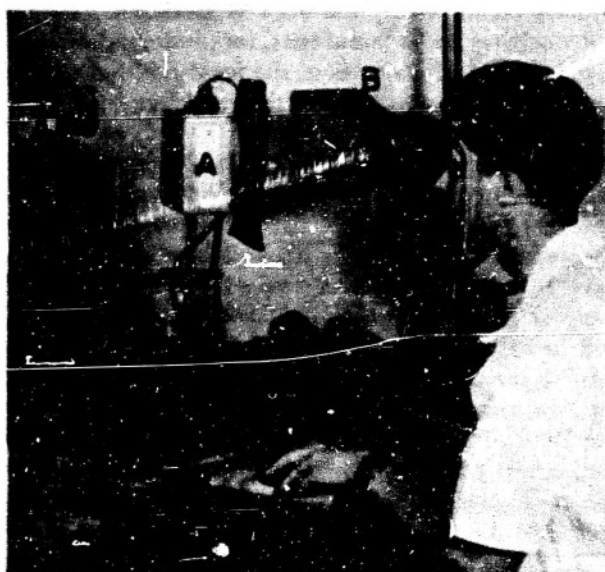


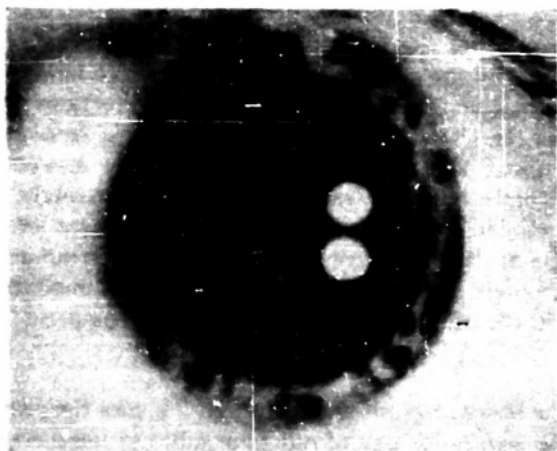
FIG. 1. Apparatus for photographing the Purkinje images for various states of accommodation. A, flash lamp covered with a double aperture, B, camera, C, accommodation-fixing test object.

was placed level with the subject's eye, on a line 30° from the visual axis, and about 30 cm from the eye. The latter distance was varied from subject to subject, to obtain maximum useable separation in the second Purkinje image of the double aperture as seen in the subject's pupil. All three Purkinje images of the double aperture were photographed by a camera (B, Fig. 1) placed about 45° on the other side of the visual axis. The camera lens had a 127 mm focal length, was used at $f/8$ and was about 20 cm from the subject's eye. For preliminary adjustments and focusing, a reflector containing an incandescent lamp and covered with a double aperture identical to that of the flash lamp was placed in the position of the flash lamp. The subject's head was held steady in a head rest. A distant fixation point was used to keep his gaze steadily oriented in the forward direction, so that the second image appeared centered in the pupil.

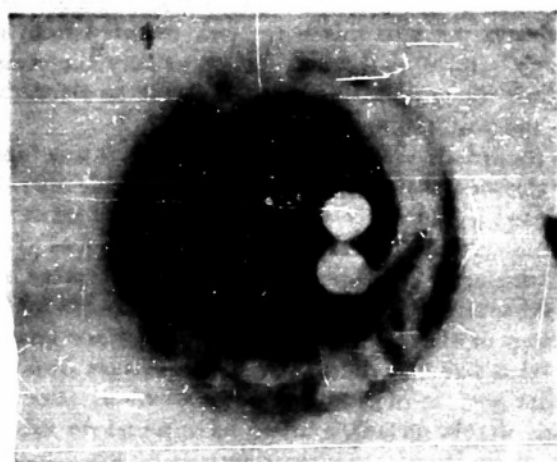
The experimental procedure was as follows: First, to determine the relation between the Purkinje image separation and accommodation, a series of flash exposures was made with the eye in various states of accommodation. These states were maintained by having the subject view a test object (C, Fig. 1) placed at various distances from the eye, and in line with the distant fixation point already mentioned. A black Landolt ring or a grating, placed on a small piece of opal glass illuminated from behind, was used for a test object. The rest of the room was kept dark, so that a large pupil was obtained. Some pupil constriction of course occurred at the higher states of accommodation. The test object was viewed binocularly to reinforce the accommodation as much as possible, but only the right eye was photographed.

After completion of the series of calibration exposures, the subject was allowed to remain in darkness for about 15 minutes, which was considered sufficient to allow accommodation, if any, to occur. A series of flash exposures in total darkness was then begun, allowing sufficient time for readaptation between each flash. The subject looked straight ahead in the dark at the point where he remembered the fixation point to lie. An occasional flash of light from the fixation point was used to refresh his memory. In a dozen or more exposures, there were always some where the Purkinje images of the double aperture occupied the same region of the pupil as that when the fixation point was viewed.

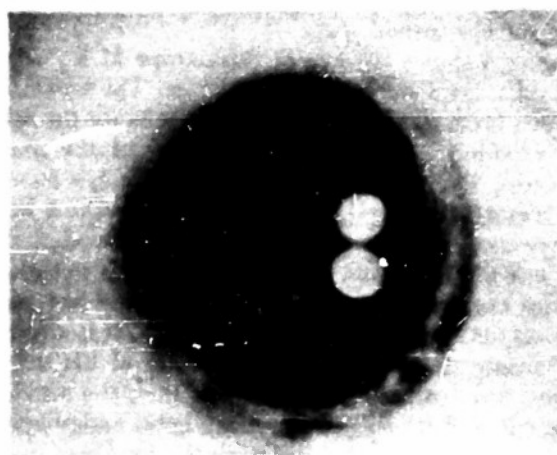
It was found that the separation between the images varied significantly when the eye turned so as to place them in different parts of the pupil although the accommodation was held constant; therefore, photographs showing the images appreciably misplaced were disregarded. Subject R.S. showed the greatest change in image separation when his eye was turned to make the images appear in different parts of the pupil. In his case, for an image separation about $\frac{1}{2}$ the diameter of the dark-adapted pupil, the image separation where one image was nearly touching the upper edge of the



(A)



(B)



(C)

FIG. 2. Photographs of Purkinje images of emmetrope R.S. under various conditions. In Fig. 2(A) the eye was focused for 5 meters (far vision), in 2(B) for 25 cm, and in 2(C) the eye was in total darkness.



(A)



(B)



(C)

FIG. 3. Photographs of Purkinje images of emmetrope M.K., who had particularly diffuse images. In Fig. 3(A) the eye was focused for 5 meters (far vision), in 3(B) for 30 cm, and in 3(C) the eye was in total darkness.

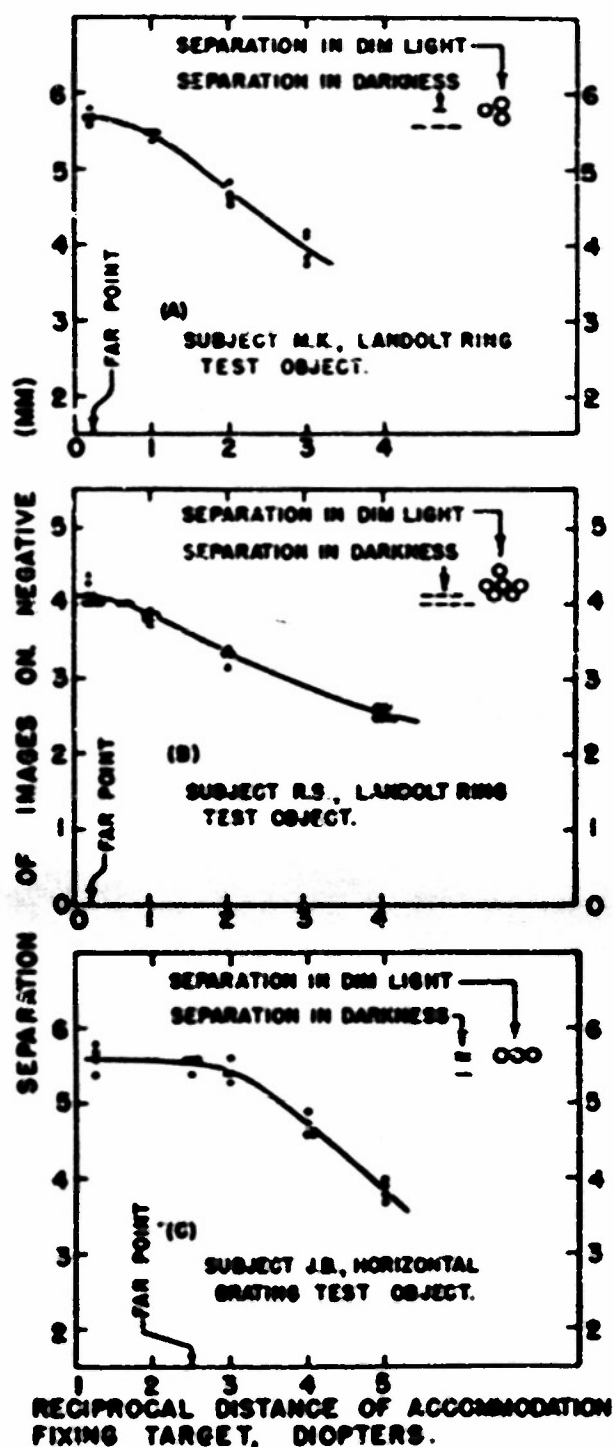


FIG. 4. Separation of the second Purkinje images of a double aperture, plotted as a function of the state of accommodation. Graphs A and B are for nearly emmetropic subjects; C is for a low myope. To the right of each graph are plotted the image separations when the eye viewed a distant, dimly illuminated scene and when the eye was in complete darkness. In the two latter cases there was no attempt to fix the subject's state of accommodation.

pupil was 20 percent greater than when one image was near the lower edge of the pupil. Lateral movement of the images in the pupil caused less variation in separation; movement from nasal to temporal edge of the

pupil produced about 7 percent increase in separation. Separation of the corneal images was not measurably changed by the eye movements above, which amounted to approximately 5 degrees in various directions from center. In the other subjects the change in separation was about 10-15 percent for the up-down movement and correspondingly less for the lateral movement of the images. In the case of R.S. misplacement of the images in the pupil could have caused an error up to 1.5 diopters in determining the state of accommodation, and in the other subjects as much as 0.75 diopter.

RESULTS

The series of photographs in Fig. 2 shows the nature of the results for one of our four subjects (emmetrope R.S.). In the first picture the eye was focused for 5 meters, in the second for 25 cm, and in the third the eye was in complete darkness. In each photograph, the image pair farthest to the right is that reflected from the cornea; next to this is the pair reflected from the anterior surface of the lens (called usually the second Purkinje image) and farthest left is the pair reflected from the posterior surface of the lens.

In confirmation of textbook statements, it was found only the second Purkinje image of the double aperture decreased significantly in separation during moderate accommodation. This separation, therefore, was taken as a measure of accommodation and the camera was focused sharply for these images. This accounts for the fuzziness of the corneal and posterior surface images. The large size and diffuseness of the images from the anterior surface of the lens seems to result from the nature of this surface, and we have found no subject where these images were sharp or circular when the eye was adjusted for far vision. With accommodation, however, the second Purkinje images became smaller and more circular, as well as closer together. It was also found that the shape of these images varied a little when the eye turned.

Figure 3 shows the eye of emmetrope M.K., whose second images were particularly diffuse. The separation between them was about twice as great as for the other eyes examined, for a given separation of the source apertures. The first photograph is for the eye focused at 5 meters, the second at 50 cm, and the third is for the eye adapted to total darkness. It will be seen that each one of the second Purkinje image pair has an irregular shape for far vision but is somewhat more compact for 2 diopters of accommodation. It is interesting to note that this subject, in spite of his diffuse images, had acuity somewhat better than the previous subject R.S. Both subjects had negligible astigmatism.

Figure 4 gives in graphical form the results of measurements on three subjects. Figure 4(A) is for the right eye of subject M.K. A routine test by an ophthalmologist indicated that, by the fogging method before cycloplegia, the eye was hypermetropic by 0.25 diopter; cycloplegia retinoscopy revealed zero refractive error,

and the cycloplegia trial case finding also showed zero refractive error. In the laboratory he preferred a spectacle correction varying between 0 and -0.25 diopter, depending upon the test object used. Astigmatism was negligible. In the graph is plotted the separation of the second Purkinje images as the reciprocal distance (in diopters) of the accommodation-fixing test object. The dashed lines, plotted to the right, indicate the image separation when the flash exposures were made in total darkness. The large circles are the separations of the image pair when the eye was viewing the very dimly illuminated far end of the room. It can be seen that these separations are essentially the same as for the eye focused for "infinity" (5 meters). It was concluded therefore that this subject did not change the curvature of the eye lens and enter an accommodated state in total darkness or dim light, but remained focused for far vision. Nevertheless, by subjective test in dim light the eye of this subject was myopic, and required a $-1.5D$ spectacle for maximum acuity at 0.02 microlambert. This myopia has already been explained¹ as a result of the aberrations of the eye.

Figure 4(B) shows the results of measurements on the right eye of observer R.S. Cycloplegia revealed from 0.5 to 1.0 diopter of latent hypermetropia in this subject, the amount depending apparently upon the depth of the cycloplegia. No hypermetropia could be elicited by other measures, such as wearing positive spectacles for long periods. His optimum spectacle correction was between 0 and -0.25 diopter in daylight without cycloplegia. Astigmatism was negligible. The plotted points in 4(B) are the separation of the second Purkinje images as the reciprocal distance (in diopters) of the accommodation-fixing test object. As in 4(A) the dashed lines indicate the image separation when the flash exposures were made in total darkness, and the circles are for exposures in dim light. Obviously, this subject too kept his accommodation relaxed in darkness and in dim light. This subject also exhibited the phenomenon of night myopia; a $-1.75D$ spectacle lens was the most positive that would give maximum visual acuity at 0.02 microlambert. We conclude again that this night myopia was not the result of accommodation, but to aberrations in the eye.

Figure 4(C) shows the results of measurements on J.B., a low myope with a far point about 40 cm (2.5D)

for the horizontal axis, and 50 cm (2.0D) for the vertical axis. He was a completely untrained subject. The quantities plotted are the same as in the two previous figures. This subject was not refracted under cycloplegia, and the amount of his night myopia is not known, but the data show that the focus for this eye in total darkness and dim light is that corresponding to his far point. He can therefore be classed as another subject who shows no evidence of accommodation when visual stimuli are weak or are absent.

Our fourth subject R.T., a moderate myope having a far point at 19 cm (5.25D), gave variable results. The experiment was performed with this subject on seven different occasions. On one occasion his focus in complete darkness corresponded to his far point, on another there was some evidence of slight accommodation, about 0.5 diopter, and on four occasions his eye changed focus by about one diopter in the direction of myopia, and on one occasion by 1.5 diopter. The reason for this erratic behavior is not clear, but the subject complained more than the others of difficulty in keeping his eye from wandering in total darkness, and it seems possible that he exerted some accommodative effort in attempting to keep his fixation "straight ahead." However, when the room was very dimly illuminated instead of being totally dark the accommodation disappeared or was barely measurable. Under the same conditions of dim light the subject still exhibited the subjective night myopia; a spectacle 1.5 diopter more negative than his optimum daytime correction was required to give him maximum acuity at 0.02 microlambert. The myopia obviously cannot be attributed to accommodation.

CONCLUSION

Photography of the Purkinje images of a flash source indicates that night myopia occurs in the absence of changes of curvature of the eye lens in our subjects, and we have not confirmed Otero's conclusion that increased accommodation is the major cause of night myopia. The optical aberrations in the eye were found adequate to account for the night myopic condition. A review of the literature, together with our own results, leads us to believe that accommodation is seldom an important cause of the phenomenon.